GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 1/19/81

Project Title: Entrance and Exit Flows in Polymer Processing Equipment

Project No: E-19-639

Project Director: Dr. A.P. Yoganathan

Sponsor: E.I. DuPont de Nemours & Company, Inc.; Wilmington, DE 19898

Agreement Period: From 1/8/81 Until 4/7/81 (Perf.) 5/30/81 (Rpts.)

Type Agreement: Unnumbered Letter dated 1/6/81

Amount: $8,700

Reports Required: Final Report

Sponsor Contact Person (s):

Technical Matters

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E.I. DuPont de Nemours & Company, Inc.
Wilmington, Delaware 19898

Contractual Matters
(thru OCA)

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E.I. DuPont de Nemours & Company, Inc.
Wilmington, Delaware 19898
302/774-1744

Defense Priority Rating: None

Assigned to: Chemical Engineering (School/~~Laboratory~~)

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SR-2227

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 7/22/81

Project Title: Entrance and Exit Flows in Polymer Processing Equipment

Project No: E-19-639

Project Director: Dr. A. P. Yoganathan

Sponsor: Dupont; Wilmington, DE

Effective Termination Date: 4/7/81

Clearance of Accounting Charges: 5/30/81 (reporting)

Grant/Contract Closeout Actions Remaining:

NONE

- _ Final Invoice and Closing Documents
- _ Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ____________

Assigned to: Chemical Engineering (School/~~Laboratory~~)

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Other: M. Passafiume

REPORT TO THE POLYMER
TECHNOLOGY RESEARCH GROUP,
ENGINEERING TECHNOLOGY LABORATORY

E.I. Du Pont De Nemours and Company
Wilimgton, DE. 19898

(1/8/81 - 4/9/81)

Professor Ajit P. Yoganathan

School of Chemical Engineering
Georgia Institute of Technology
Atlanta, GA. 30332

INTRODUCTION

The report describes briefly my experience during my 3 month stay (1/10/81 - 4/9/81) in the ploymer group at ETL. I worked on two projects work done during my short stay I felt that I had learned a great deal during my visit. The visit gave me an opportunity to see how industrial research was conducted as opposed to academic research. I was able to meet and talk with many people in the polymer processing area. I am hopeful that I will maintain a continuing working relationship with the polymer group at ETL. There are definitely areas of mutual research interest.

I worked with Drs. G.W. Goldman and J.D. Trentacosta on laser-Doppler studies of flow instabilities in a two-dimensional capillary die. The model we used was a magnified scale of a meter plate/spinnert cavity. The objective was to study the flow differences and instabilities with Newtonian and viscoelastic fluids. Clear differences were observed between the Newtonian and viscoelastic fluids used in the study. A brief description of the apparatus, methodology and results obtained during this project are given in the following pages. Ideas for further work in this area are also stated.

On a secondary project I worked with Dr. R.S. Heckrotte on Nomex spinpack studies. Due to time delays in obtaining the plexiglass pack model, all that could be done was setting up the equipment for studying residence time distributions in the pack model. At the time I left the spinnert plate had not yet arrived, so we ran some mock experiments with a sintered metal plate as a substitute.

I wish to thank Dr. Paul Tebo and Mr. Richard Koffenberger for arranging my visit. I would also like to thank the polymer group at ETL for making my stay at DuPont a very interesting and stimulating experience.

APPARATUS & METHOD

Experiments were conducted in a two dimensional model capillary die with a 60° entrance angle (Fig. 1). Detailed engineering drawings of the model capillary are given in appendix #1. The capillary was machined out of aluminum and had a plexiglass cover plate. The transparent cover plate was necessary since optical techniques were used to study flow fields in the model capillary.

Laser-Doppler anemometry was used to study the velocity fields in the model capillary. A TSI one color (15 mW He-Ne Laser) modular LDA system was used. The system incorporated Bragg-Shift, a beam expander, a 120 mm front lens and was operated in the back-scatter mode. Signal analysis was done on a Marconi spectrum analyzer. The laser-Doppler system was placed on a elevating hydraulic table, while the capillary model was placed on a small x-y traverse (see Fig. 6). Therefore, velocity measurements could theroretically be made at any position within the capillary. Due to signal-to-noise problems, however, velocity measurements could only be made to a depth of about 25 mm from the inside surface of the cover plate. The model had a total depth of 50.8 mm. With powerful low and high-pass filters the noise could be filtered, there by making velocity measurements across the entire depth possible. Such filters were not, however, available for the present study. In addition to the velocity measurements, the flow field was visually observed by various lighting techniques.

Corn-syrup(83% by weight in water) and Separan AP-30 (2%, 1% and 0.5% by wt. in water) were used as the test fluids. The corn-syrup solutions was Newtonian with a viscosity of about 6.5 Poise. The Separan solution were highly viscoelastic and their rheological characteristics are shown in Fig. 2, 3, 4&5. These measurements were made by Dr. Vassilatos in a cone-plate geometry rheometer. 2 μm silicone carbide or 5 μm polystyrene beads were added in very low concentrations to the solutions to act as light scattering agents. The solutions were pumped at room temperature from a five gallon pressurized Binks tank. By varying the pressurization in the tank the flow rate through the capillary was varied. For each solution, the flow rates at different pressures were obtained by calibrating the flow system with a measuring cylinder and stop watch. The solutions pumped from the Binks tank were collected in a return vessel by damming the capillary exit as shown in the photograph in Figure 6. When the Binks tank was empty the solution in the return vessel was poured back into the Binks tank. The Binks tank provided very steady flow and was used to obtain high flow rates (10 cm^3/sec and larger). Depending on the flow rate, the tank could empty itself within about 3 to 5 minutes. This was a major disadvantage, but could be overcome by using a larger tank.

Experiments with the corn syrup solution were conducted over a flow rate range of 20 to 40 cm^3/s, while the Separan solutions were studied over a range of 20 to 80 cm^3/s. Due to the higher viscosity of the corn syrup solution it was not possible with the present pumping apparatus to increase the flow rate of this solution. The Binks tank could only be pressurized to a maximum of about 70 psi.

RESULTS & DISCUSSION

Examples of the experimental measurements obtained at three different flow rates for the different fluids are shown in Figures 7 through 18. These measurements were made at a depth of about 10 mm from the inside surface of the cover plate. Experiments were also performed at depths of 5 mm and 24 mm from the cover plate at the same flow rates. In all experiments the flow upstream was fully developed and undistrubed. Examples of the fully developed flow fields are shown in Figure 19 for the corn syrup and 2% Separan solutions.

The results from these preliminary results indicate very clearly that the Newtonian corn syrup solution exhibits stable and undistrubed flow fields (streamlines and velocity profiles) throughout the entrance and land regions of the 60^{o} capillary (see Figs. 7, 8&9). The maximum Reynolds number for the corn syrup experiments based on the upstream geometry was 2.4. The flow streamlines faithfully followed the contours of the capillary geometry and no regions of disturbed flow were observed either in the velocity profiles or flow visualization studies. In addition, the velocity measurements made at the various depths from the cover plate indicated quite clearly Newtonian type velocity profiles across the depth of the capillary geometry.

The three Separan solutions, however, displayed very non-Newtonian behavior. The results were surprising at first, but on second thought were physically realistic. Figures 10 through 18 show the velocity profiles obtained with the different solutions. Figures 10, 13 and 16 also show schematics of the flow field (author's conception) for the three Separan solutions in the entrance and land regions of the capillary. These schematics were drawn from the velocity measurements made at the different flow rates and at the various depths, as well as the flow visualization studies made by the author during the period the experiments were conducted.

For the 2%, 1% and 0.5% Separan solution varying the volumetric flow rate (20 to 80 cm^3/s), or the depth of measurement of the velocity profiles from the cover plate (5 to 25 mm), did not seem to affect the dimensions of the flow separation regions shown schematically in Figs. 10, 13&16, respectively, by more than $\pm$ 1 mm. This variation is within the experimental error of the present study. All three Separan solutions showed regions of flow separation which extended from the entrance region through the land region of the capillary. In the case of the 1% and 2% Separan solutions the flow separation extended all the way to the capillary exit. Due to the lack of time and experimental difficulties experiments were not conducted at flow rates lower than 20 cm^3/sec.

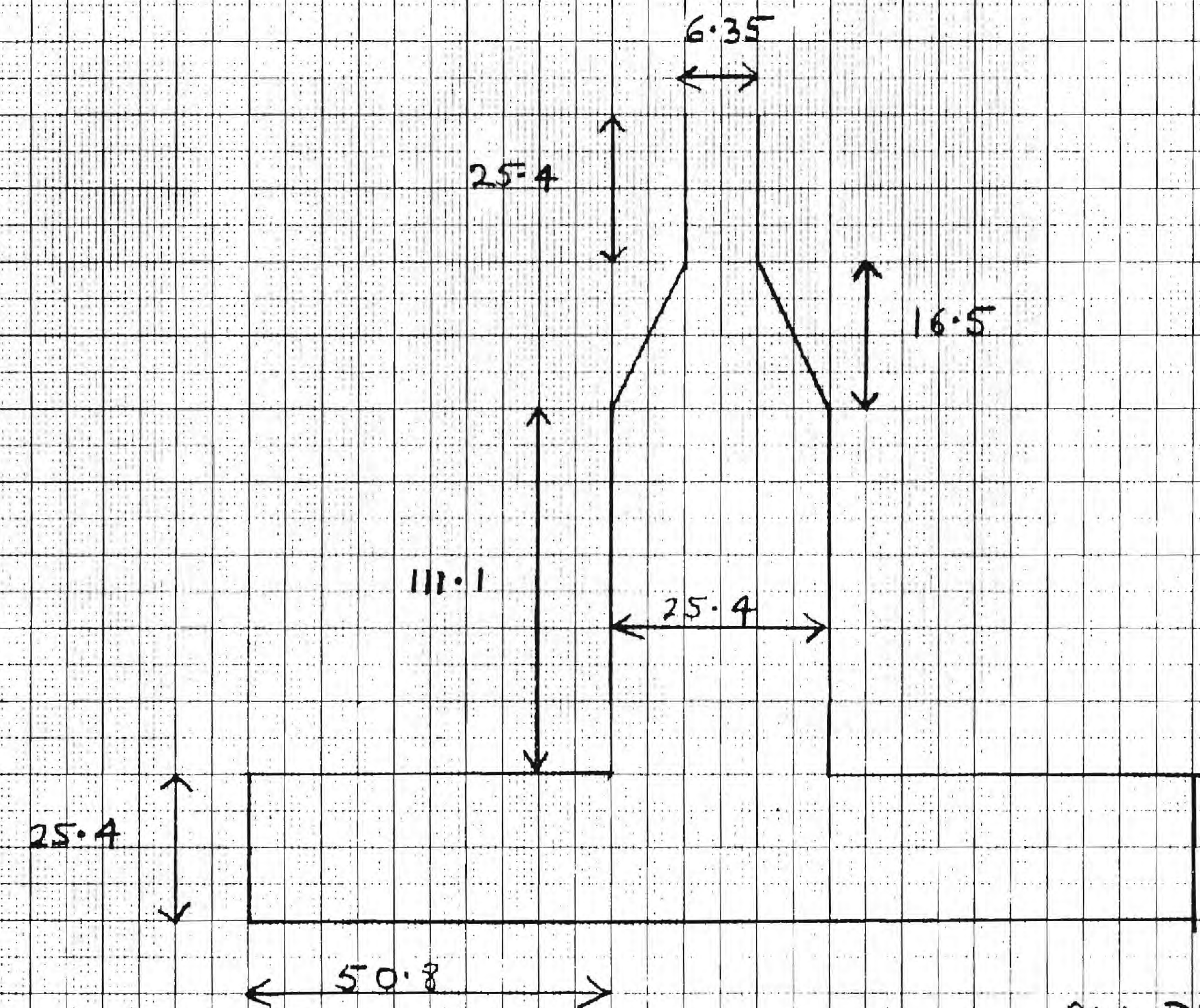
The results of this preliminary study show very clearly that the highly viscoelastic and non-Newtonian nature of the Separan solutions (see Figs. 2-5) create very different flow fields compared to a Newtonian fluid with approximately the same shear viscosity and at the same volumetric flow rates. The regions of flow separation created by the Separan solution would be very undesirable in a polymer processing operation, since the polymer in the flow separation regions would degrade with time. Depending on the polymer being used, its rheological characteristics, and the volumetric flow through the system, the entrance region to the capillary die should be tailor-made so as to avoid undesirable flow behavior such as flow separation. In the case of the Separan solutions an entrance angle of 120^o would have been more suitable. Such an entrance angle may have reduced and/or eliminated the flow separation regions observed in the present study.

CONCLUSIONS

The highly viscoelastic and non-Newtonian characteristics of the Separan solutions created undesirable flow fields in the entrance and land regions of the capillary die. Separan solutions (at room temperature) have rheological characteirstics similar to certain polymer melts at temperatures of about 200°C.

However, due to the preliminary nature of the present study it is not possible to directly and quantitatively correlate the rheological characteristics of the polymeric fluids to the measured flow fields. In order to do this further detailed experiments will have to be carried out. In addition, future studies should be conducted in a properly scaled cylindrical capillary geometry to simulate the real-life situation. The scaling factors used in the present study were very satisfactory. It is quite possible that the cylindrical geometry could greatly influence the flow fields observed in the present study. Even though optical problems may be encountered with a cylindrical geometry they can be overcome with appropriate optical tricks. If the polymer group at ETL is interested I would be willing to design the cylindrical capillary geometry so as to minimise optical problems. In addition, appropriate electronic filters should be constructed so as to improve the singnal processing capabilities of the laser-Doppler anemometer system.

This preliminary study was very enlightening and useful to understanding the flow polymeric fluids in capillary geometries. It is the hope of the author that the work will be continued on an on-going basis by the polymer group at ETL. The author hopes that in the near future he will be able to submit a joint university-industry proposal to the National Science Foundation for similar work of mutual interest to DuPont and to Georgia Tech.



ALL DIMENSIONS IN MM
NOT TO SCALE.

FIG. 1.

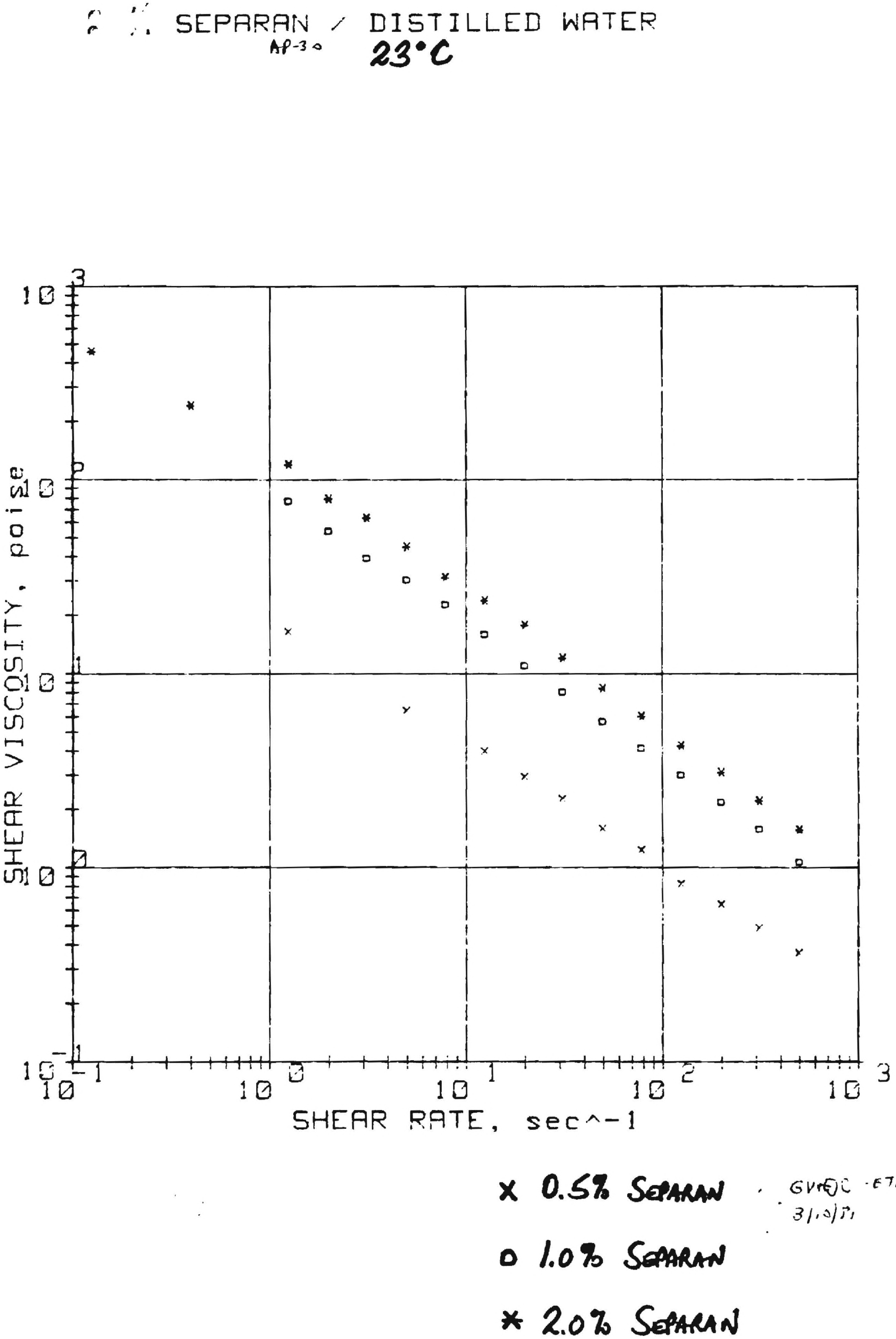
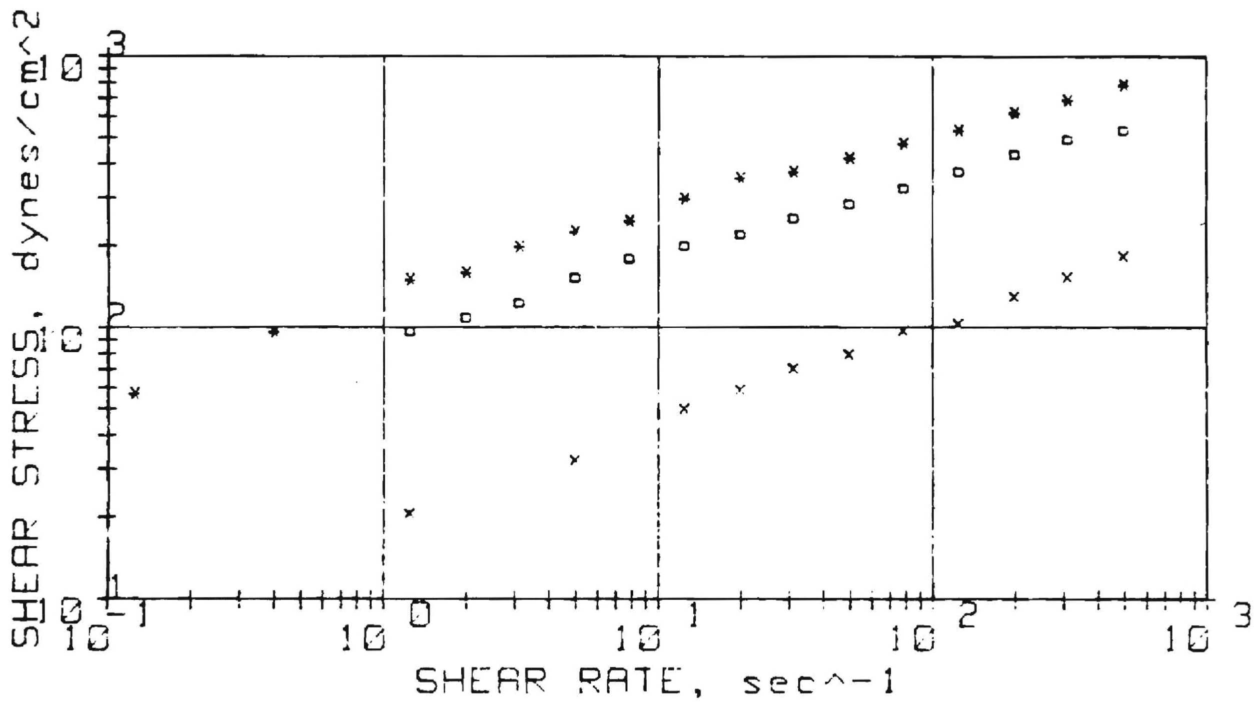

SEPARAN / DISTILLED WATER
AP-30
23°C
SHEAR VISCOSITY, poise
SHEAR RATE, sec^-1
x 0.5% SEPARAN
o 1.0% SEPARAN
* 2.0% SEPARAN

FIG. 2

2 % SEPARAN / DISTILLED WATER
AP-3a
23°C



x 0.5% SEPARAN

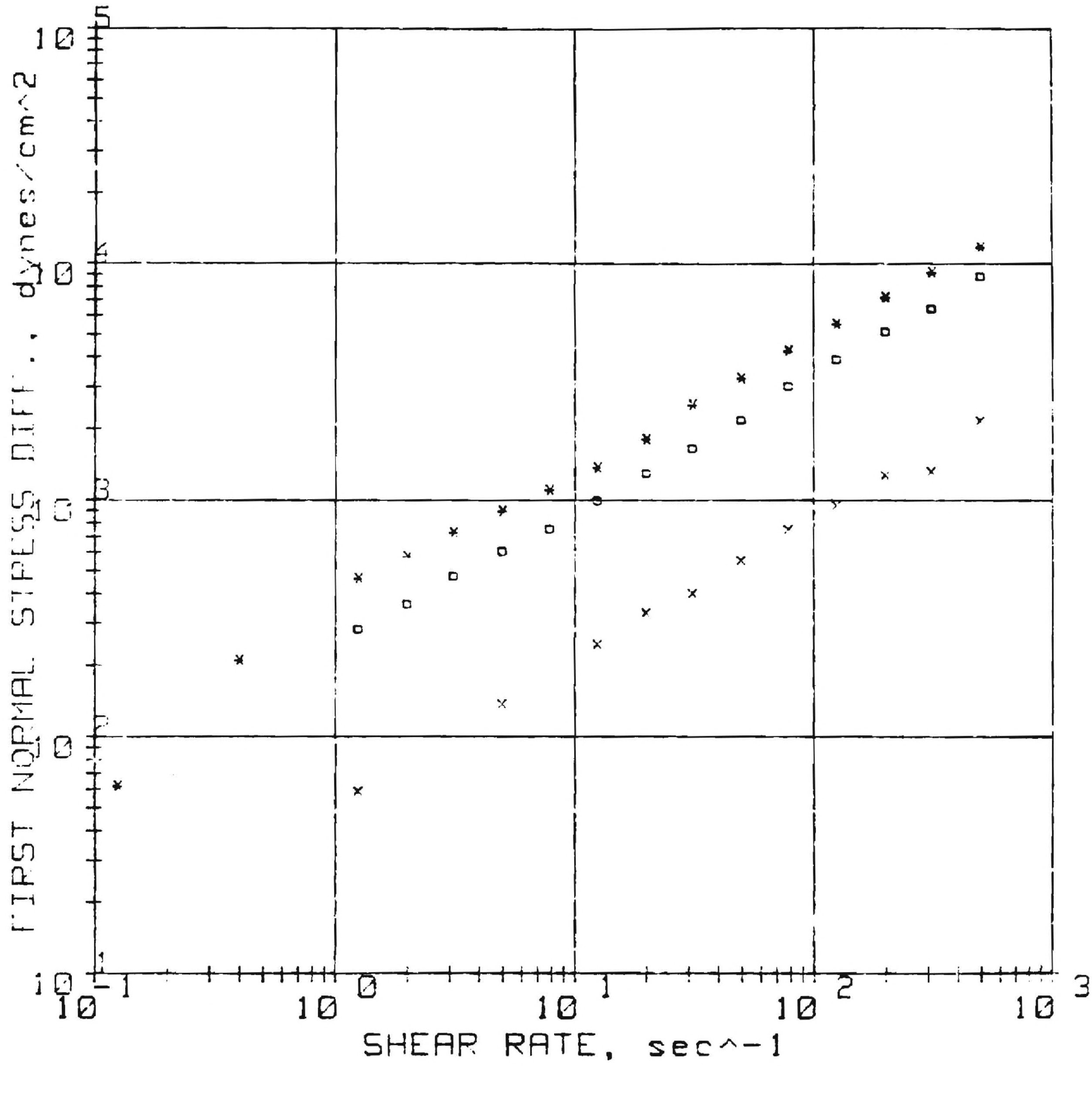
o 1.0% SEPARAN

* 2.0% SEPARAN

GY-EJC-ETL
3/10/81

FIG. 3

2 % SEPARAN / DISTILLED WATER
AP-30
23°C



x 0.5% SEPARAN

□ 1.0% SEPARAN

* 2.0% SEPARAN

FIG. 4

2 % SEPARAN / DISTILLED WATER

AP 3?

23°C

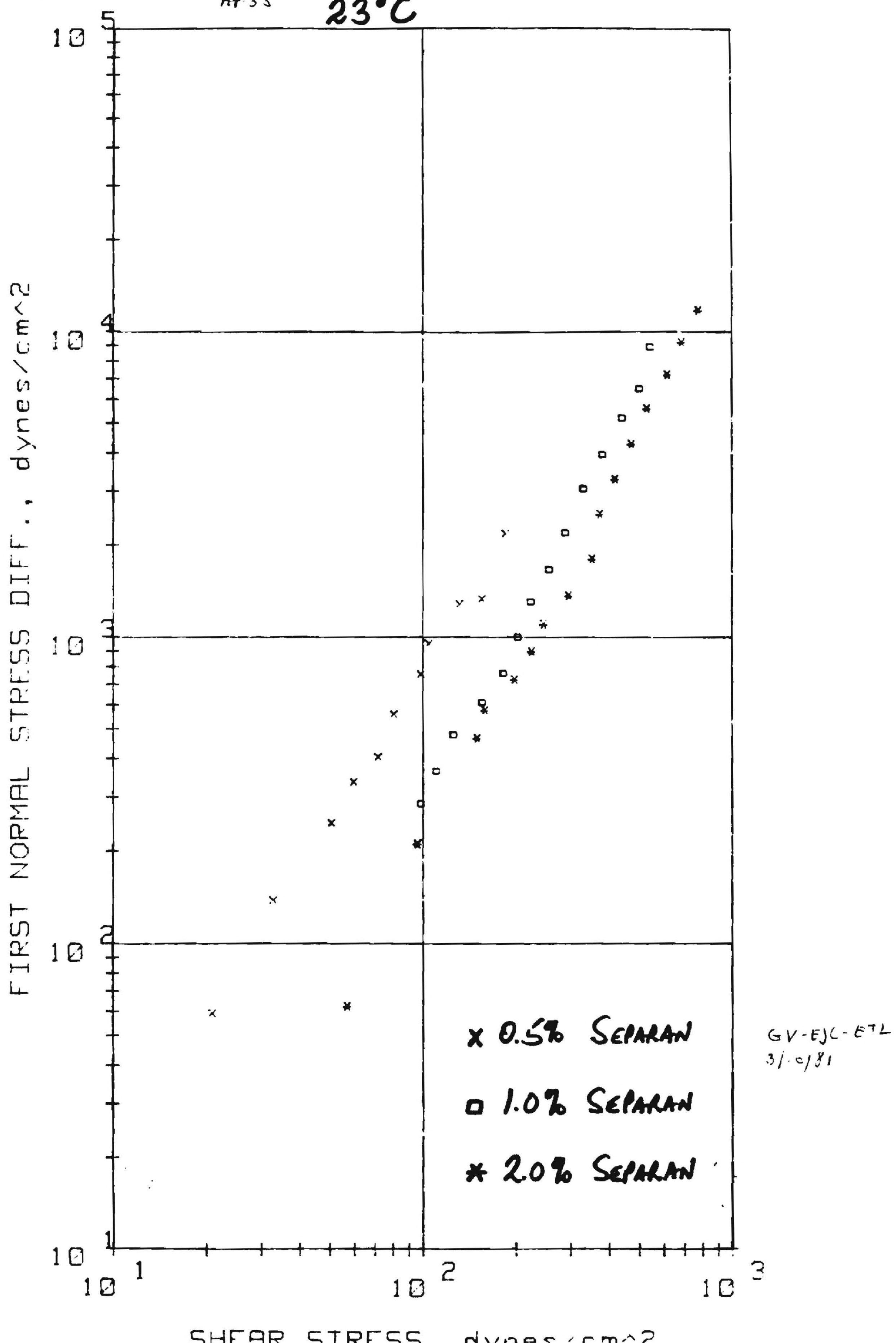


FIG. 5

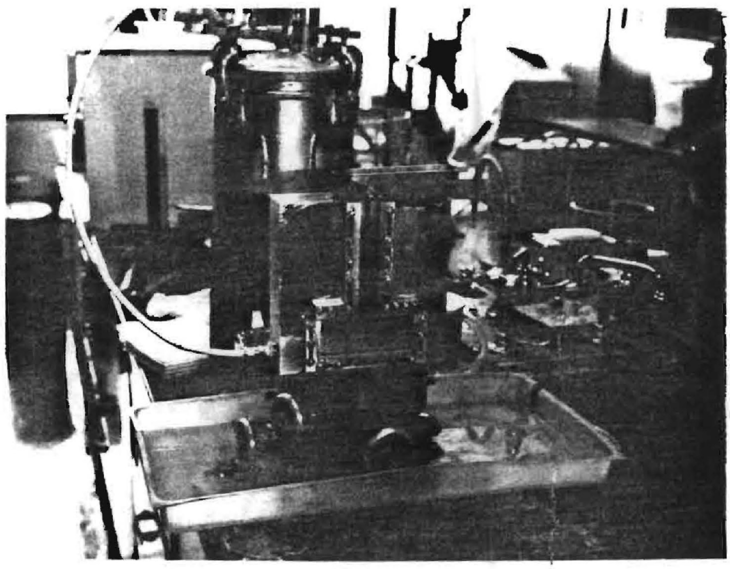
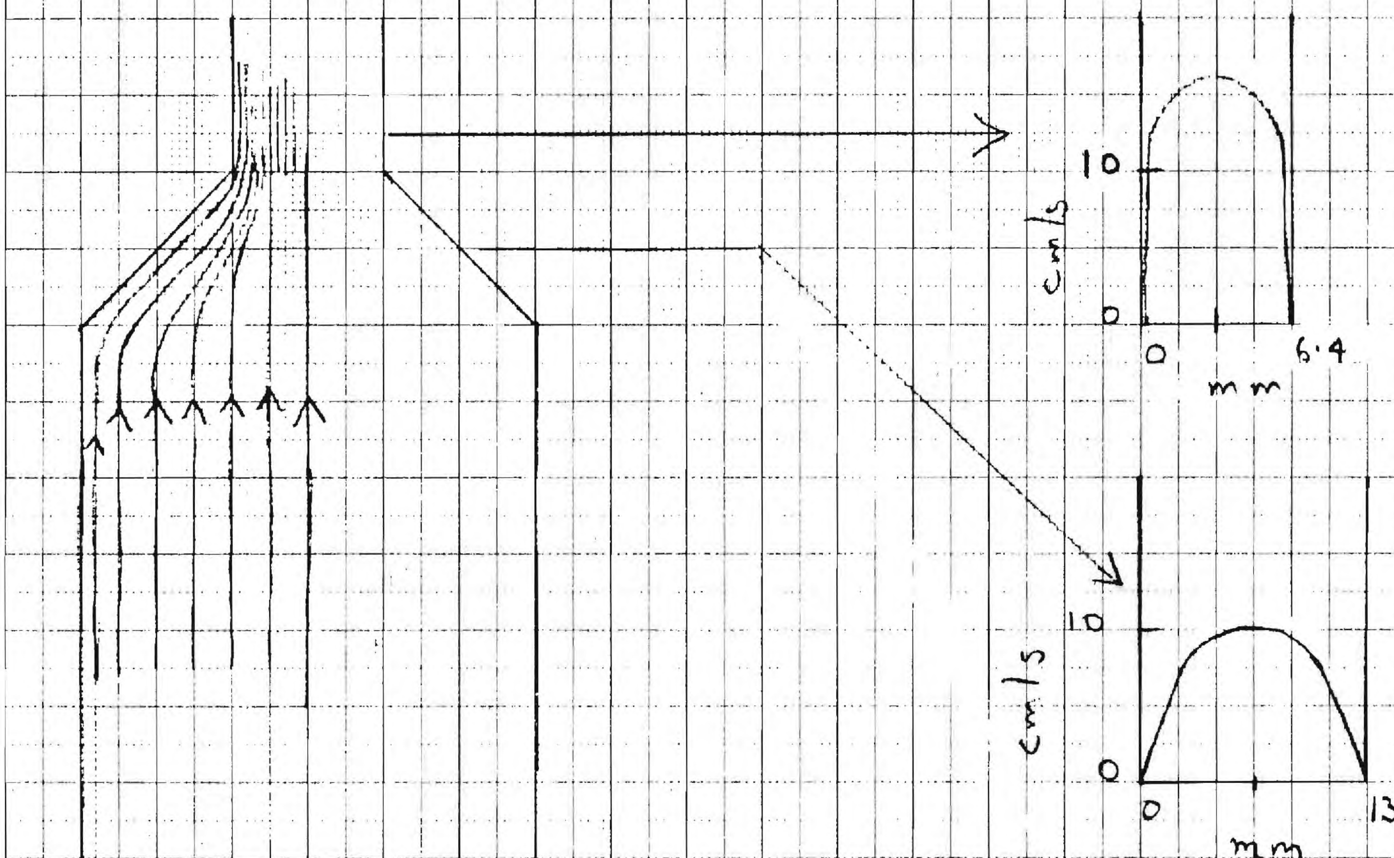


FIG 6

GOLDEN SYRUP - 83% by wt in water

$\mu \simeq 6.5$ P

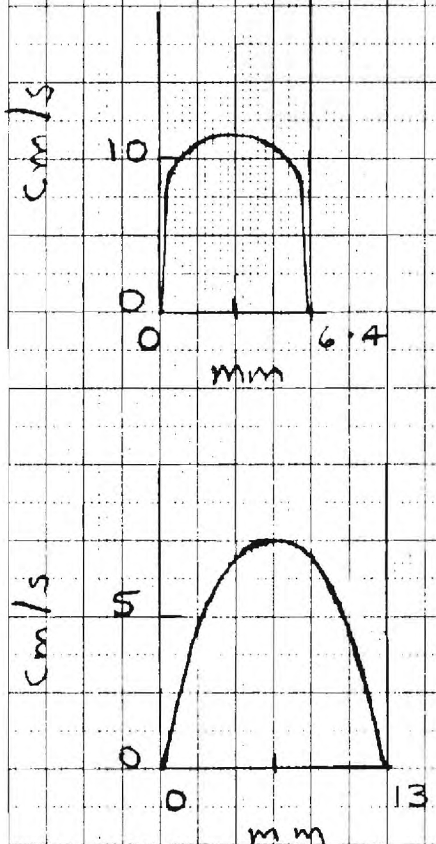


40 cm³/sec

40 cm³/s

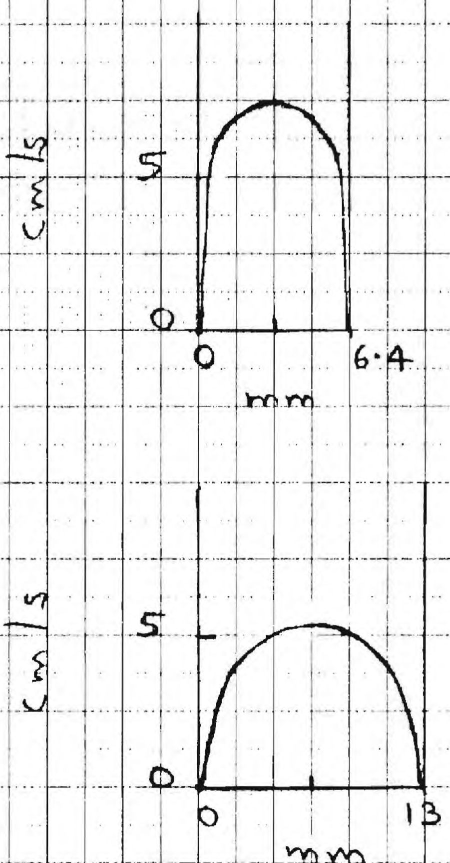
NOT TO SCALE

FIG. 7



30 cm^3/s

FIG. 8



20 cm^3/s

FIG. 9

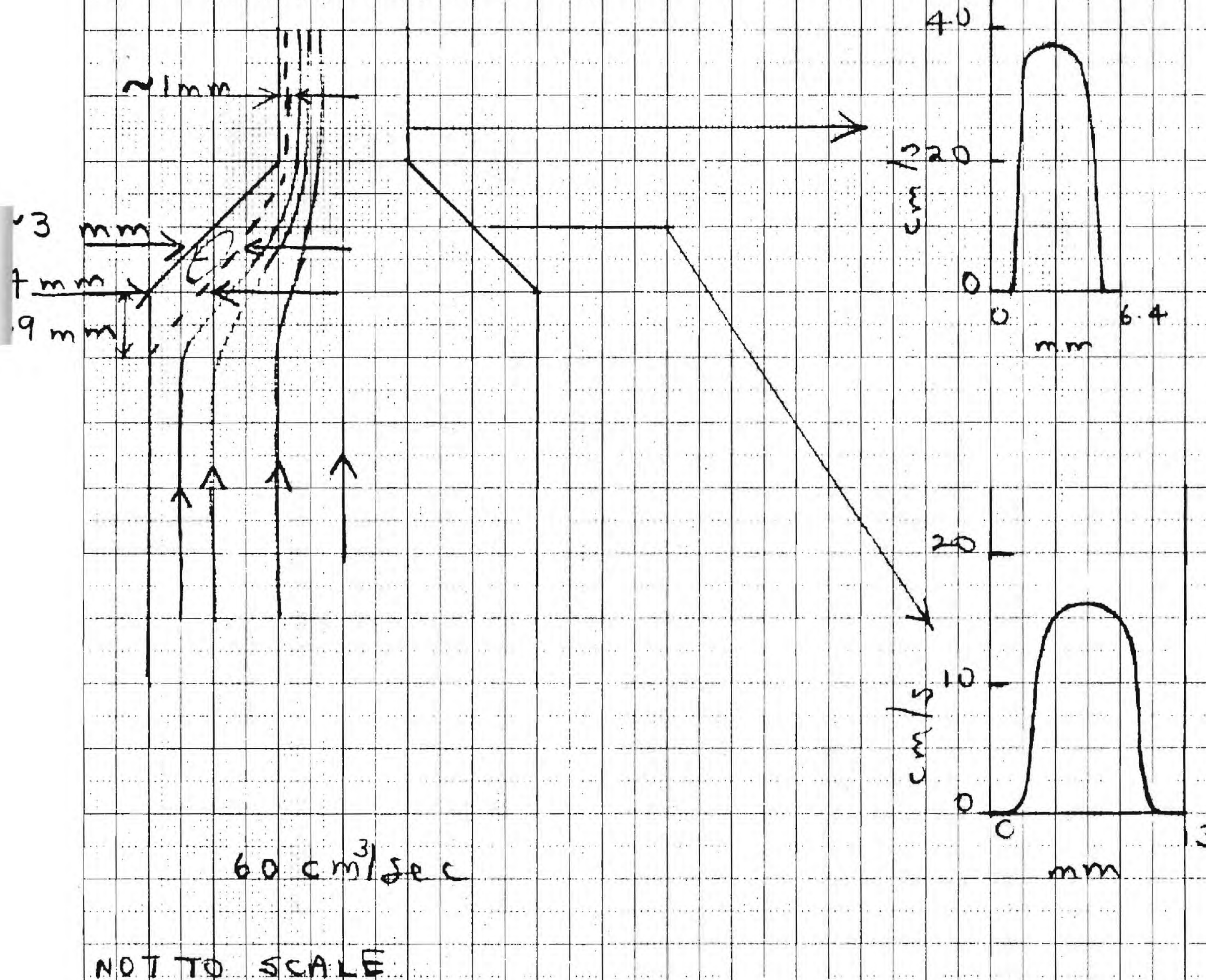
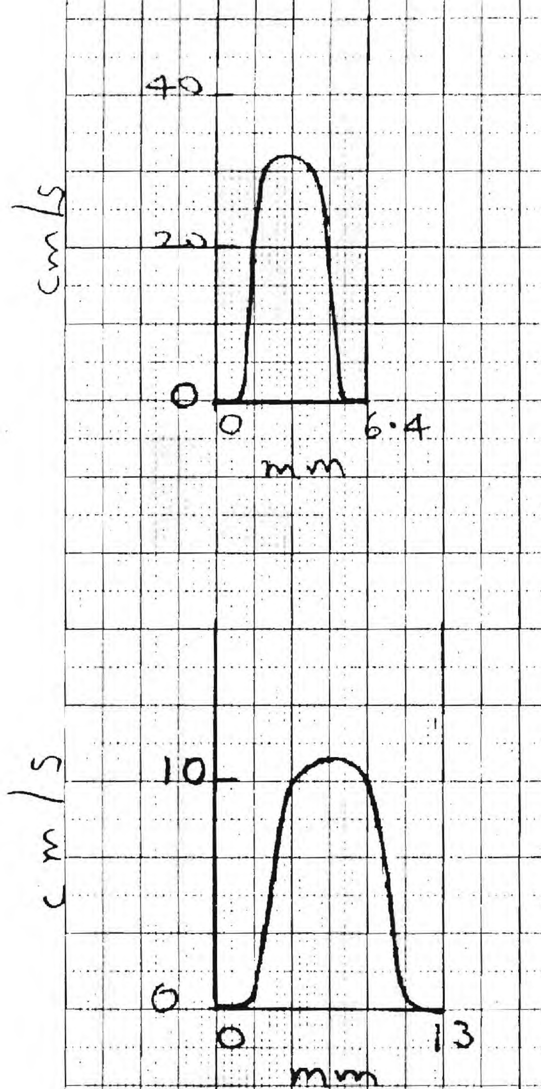
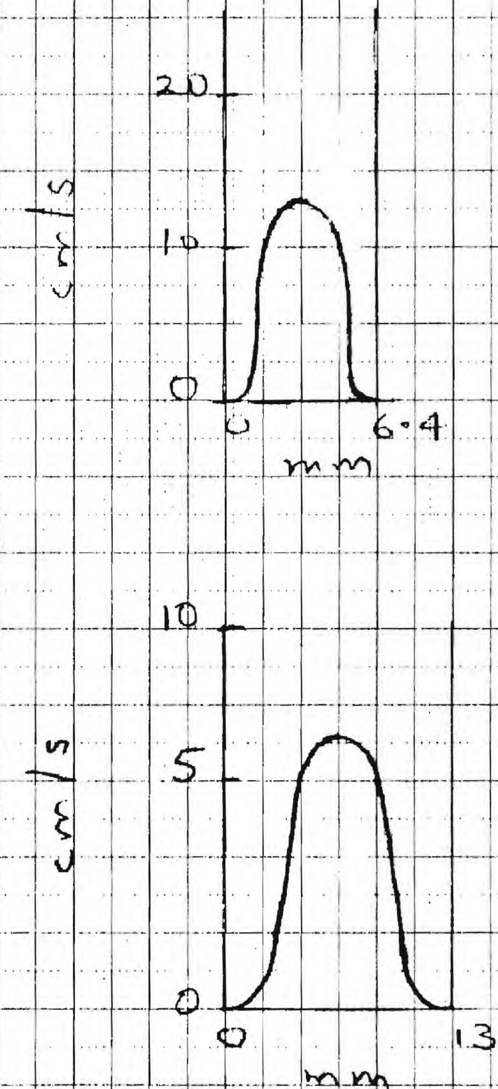

~1mm
~3 mm
~4 mm
~9 mm
60 cm³/sec
NOT TO SCALE
40
20
0
cm/s
0
6.4
mm
20
10
0
cm/s
0
13
mm

FIG. 13



40 cm^3/s

FIG. 14



20 cm^3/s

FIG. 15

SEPARAN – 0·5% by wt in water

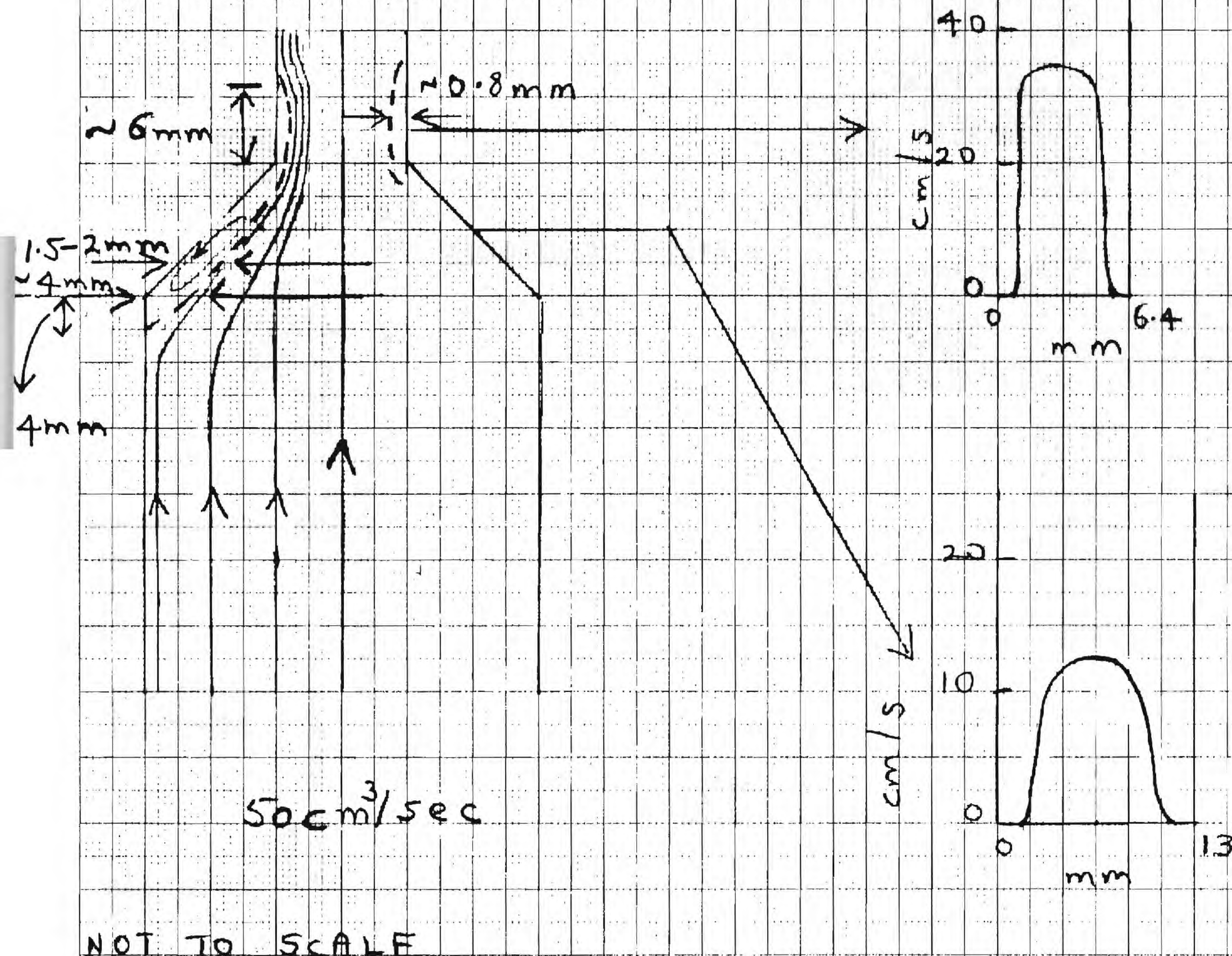
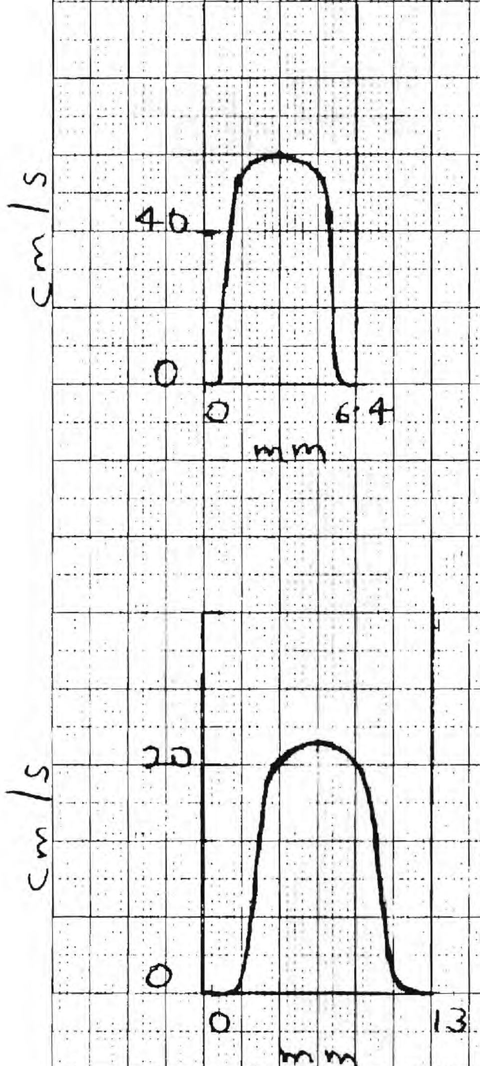
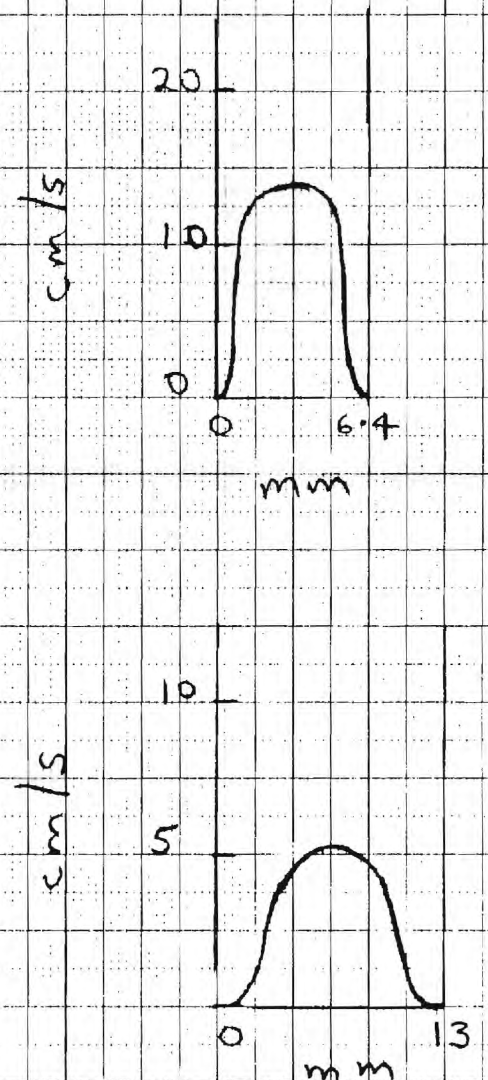


FIG. 16



80 cm³/s

Fig. 17



20 cm³/s

Fig. 18

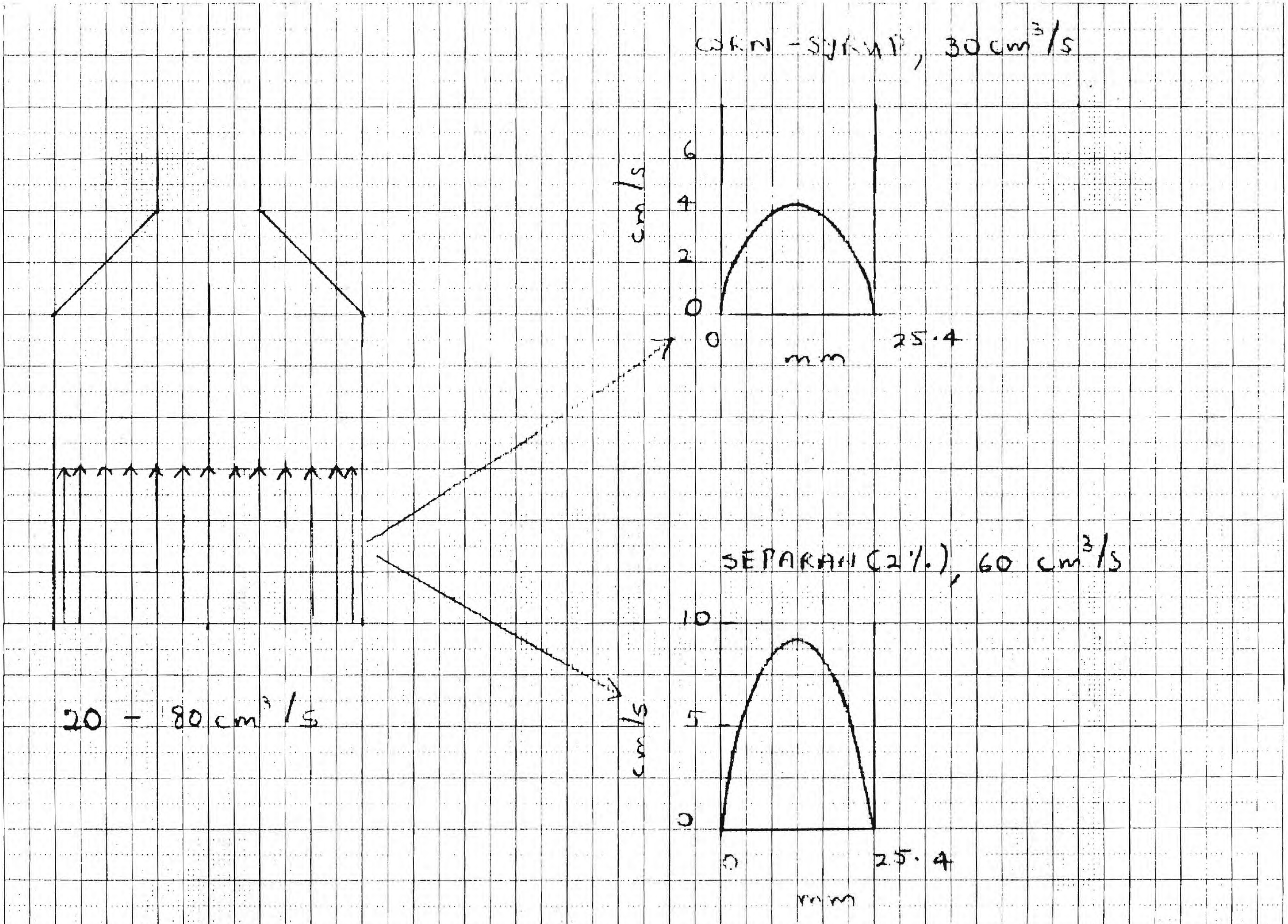


FIG. 19 VELOCITY PROFILE IN FRONT OF THE